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Intuitive Speech-based Robotic Control

by Elizabeth S. Redden, Christian B. Carstens, and Rodger A. Pettitt

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Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5425

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Human Research and Engineering Directorate, ARL

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14. ABSTRACT We conducted a speech-based robotic control study using 29 Soldiers recruited from Fort Benning, GA. Findings indicated Soldiers were able to perform a secondary task (writing numbers) significantly faster when operating a robot using speech control versus using manual control. This demonstrated that robotic control requires multitasking and also implies that speech control requires less attention than manual control, thus freeing up cognitive resources for additional tasks. Speech control allowed significantly faster performance when the task involved using menu items (enlarge picture, shrink picture). Speech control allowed direct access to the menu items, whereas manual control required navigating through a menu and selecting an item two levels deep into the menu. Speech control was also significantly faster for labeling items where Soldiers had to choose and select from a list to label a picture. Alternatively, speech control took significantly longer when performing continuous tasks, such as turning the robot during the "take a picture" task and driving to the blue waypoint, which involved a significant amount of turning. When interpreting the results, one should consider that the intuition and speech-control portions of the experiment featured tasks that could be found in a robotic reconnaissance mission and the findings are specific to these tasks.				
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1. Introduction

1.1 Statement of the Problem

Two previous studies conducted by the U.S. Army Research Laboratory's (ARL) Human Research and Engineering Directorate (HRED) indicated that the degree of effectiveness of speech-based control may be dependent upon the task being performed (Cassenti, Kelley, Swoboda, and Patton, *in press*; Pettitt, Redden, and Carstens, 2009). The goal of the present research was to examine the effectiveness of speech control for the specific tasks used in robotic reconnaissance missions.

1.2 Robotic Control

As robots become more complex and able to perform multiple simultaneous tasks, menus become more layered, and speech recognition systems become more sophisticated, verbal control of robots appears to offer great potential to bridge the gap between teleoperation and full autonomy. An important consideration for optimal design is the identification of tasks that are more efficiently performed by speech control and those that are more efficiently performed by manual control.

Conventionally, robots are controlled with manual input devices such as joysticks, touch screens, and trackballs. While these devices are ubiquitous and have been used in countless applications, they come with their own set of problems when used to control robots in operational settings. Some robots are large; some require operation from stationary positions; many require dexterity, hand-eye coordination, significant training, and practice time; and all require the use of at least one hand. Alternatively, speech control has been demonstrated to provide many benefits. The following list of strengths associated with speech control is representative of those found in the literature (Chen, Hass, Pillalamarri, and Jacobson, 2006; Bortolussi and Vidulich, 1991; Steeneken, 1996; Bourakov and Bordetsky, 2009; Graham and Carter, 2006; Pettitt, Redden, and Carstens, 2009; and Sams, 2009):

- Is more effective than manual control for menu navigation (does not require navigation through several menu layers to access the desired item).
- Is quicker and more accurate than manual control for selection of options.
- Enhances time-sharing efficiency when used in conjunction with manual controls.
- Is hands free and eyes free.
- Reduces adverse effects of mobile device operation on primary task performance (i.e., driving, walking, etc.).

- Is effective for performance of simultaneous tasks (e.g., lowering the robotic arm while driving forward).
- Is intuitive if commands are tailored to the target audience.

Since speech-control systems are in their infancy, they also come with problems. The following is a representative list of weaknesses of speech control found in the literature (Chen et al., 2006; Noyes, Baber, and Leggatt, 2000; Myers and Cowan, 2003; Steeneken, 1996; Henry, Mermagen, and Letowski, 2005; Vloeberghs, Verlinde, Swail, Steeneken, and South, 2000; Graham and Carter, 2006; Cassenti, Kelley, Swoboda, and Patton, *in press*; Pettitt, Redden and Carstens, 2009; and Sams, 2009):

- Speech control is often infeasible in environments found in the military (i.e., stealth missions; high noise, high g-force, and vibration environments; impulse and variable noise environments; environments in which echoes, reverberation, and cross-talk are present; etc.).
- Communication between team members can sometimes be misinterpreted as voice commands.
- Speaker dependent speech recognizers require long training periods when the vocabulary consists of hundreds of words, while speaker independent speech recognizers generally have lower accuracy than speaker dependent ones.
- Speaker changes caused by the Lombard effect (the increase in vocal effort when a speaker is in a noisy environment), stress, fear, sickness, whispering, pain, “incorrect” use of grammar, wearing oxygen and gas masks, etc., cause word error rates to increase.
- Explicit feedback of recognition results has been found to be necessary.
- Speech control is not as effective as manual control for continuous tasks.

Speech control has been explored for many applications. For example, it has been examined for controlling helicopters, executing telephone and automobile functions, automating the handling of customer calls, converting spoken language into sign language, converting and analyzing large volumes of spoken material, performing computer command and query, translating or summarizing information from one language to another, creating medical records, and editing (Chen et al., 2006; Steeneken, 1996; Apaydin, 2002). In situations where equipment operators have busy eyes and hands, offloading control tasks to speech has been shown to be effective (Steeneken 1996). In order to control a robot with speech commands, the system must first be capable of recognizing the command. Automated speech recognition (ASR) systems digitize spoken words and match them against coded dictionaries. Once they are identified, the spoken information can control the actions of a system or machine (Haas and Edworthy, 2002).

Karis and Dobroth (1995) proposed that a successful human factors design of a speech recognition system should involve an early focus on the target audience for the system and the tasks they will perform, and collect performance data via simulations. Our experiment was an attempt to do just that.

The following are our hypotheses regarding speech control:

1. Speech control will be quicker than manual control when the operator must perform another task in addition to robotic control.
2. Speech control will be quicker than manual control when operators must access embedded menu items.
3. Speech control will be slower than manual control for performing continuous tasks, such as turning during a driving task.

In this study, we attempted to isolate the contribution of speech control to varying tasks associated with a robotic reconnaissance mission under differing conditions.

This experiment took place at Fort Benning, GA. Twenty-nine Soldiers from the Officer Candidate School (OCS) and instructors from the Warrior Training Center participated in the study.

2. Method

2.1 Participants

The twenty-nine Soldiers recruited from the OCS and the Warrior Training Center to participate in the study ranged in age from 21 to 47 years and had a mean time in the military of 65 months.

2.2 Apparatus and Instruments

2.2.1 Apparatus

Speech Control System

The SPEAR™ speech control technology used in this experiment was developed by Think-A-Move (TAM), Ltd. The SPEAR earpiece (figure 1) has a microphone inserted into the ear canal that captures the speech signal. A wired connection carries the signal from the earpiece and ends in a standard 3.5-mm audio jack that can be plugged into a computer soundcard. Through the design of the earpiece, the signal in the desired frequency range can be amplified, thus restoring the quality of the captured speech. A proprietary speech command recognition (SCR) system is used to identify the command spoken by the user. The SCR system collects the captured speech signal and sends out a recognized command. TAM has trained specialized models tuned for

recognition of in-ear speech and the recognition accuracy target has been set to more than 90% even in extreme conditions, which include battlefield conditions where the operator is involved in intense physical activity, with loud noise in the background.



Figure 1. SPEAR earpiece.

Operator Interface

The operator interface that controlled the simulated robot used during this experiment was based on SSC Pacific's Multi-Robot Operator Control Unit (MOCU) and TAM's speech command library. An example screenshot of the interface is found in figure 2. The robot's location, driven path, goal points, and sensor data (i.e., map data) are overlaid on an aerial image. Various button controls and a joystick on a commercial-off-the-shelf (COTS) wireless game controller (the Microsoft Xbox 360 wireless controller) were used for manual control of the robot. A speech window was also provided so the operator could verify the accuracy of the speech command recognition.

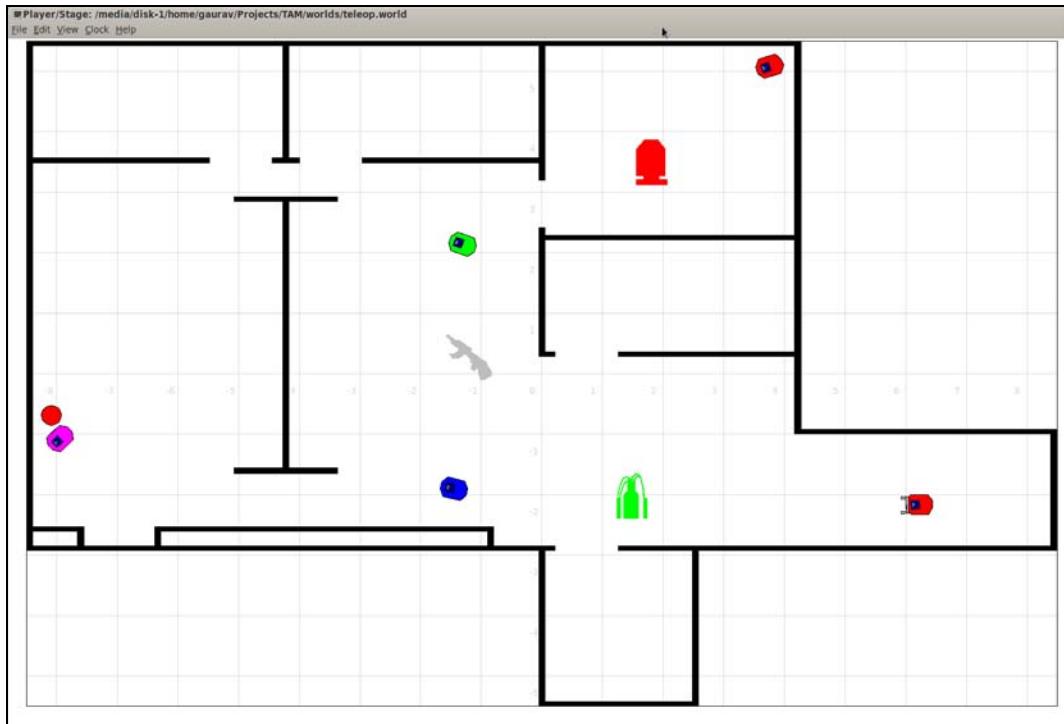


Figure 2. Snapshot of MOCU interface.

2.2.2 Instruments

Control Intuitiveness Test

The control intuitiveness test that was performed in this experiment is roughly based on an icon intuitiveness study done by Nielsen and Sano (1994), which was performed during the usability evaluation of Sun Microsystems' internal Web. In the study, images were presented to users who were asked to indicate what functionality they thought the icons represented. In a like fashion, the control intuitiveness test presents a task to naive users and then asks them to get the robot to perform the task using speech when they have had no prior training or knowledge of the correct word or phrase to use. The administrator documents the incorrect attempts to perform the task and notes the specific words that are incorrectly used. After this attempt, the administrator provides them a list of correct commands and then asks them to perform the same tasks that were presented in the initial presentation. The administrator again notes the incorrect attempts to perform each task and notes the specific words that are incorrectly used.

Questionnaires

The questionnaires were designed to elicit Soldiers' opinions about their training and experiences with each of the control systems. The questionnaires asked the Soldiers to rate the devices on a 7-point semantic differential scale ranging from "extremely good/easy" to "extremely bad/difficult."

2.3 Procedures

2.3.1 Demographics

Demographic data was taken for each Soldier. Data concerning their physical characteristics and experience, especially their knowledge of operating remote controlled vehicles, was included in the demographic data sheet shown in appendix A.

2.3.2 Control Intuitive Test

Each Soldier was seated and asked to perform the control intuitive test described in section 2.2.2. The Soldier was informed that the purpose of the task was to investigate the words that Soldiers would intuitively use to instruct the robot to perform tasks in specific situations. First, the Soldier was presented a situation and then was asked which words (short and precise instructions) he would use to get the robot to perform the needed task.

2.3.3 Training

No specialized experience was required from the requested Soldiers. Representatives from TAM trained the Soldiers on how to use the robotic simulation, which included both manual and verbal control of the robot. Training questions were included in the post iteration questionnaire so that Soldiers had the opportunity to comment on adequacy of training and provide suggestions for improving the training course.

2.3.4 Speech Control Tasks

After completion of the intuitive test, the Soldiers were asked to perform a series of tasks to assess the contribution of speech control for that task. Tasks were performed using both speech control and manual control. Photographic tasks required the Soldiers to take a picture of an object (an AK-47 and a bomb), label the pictures, enlarge the pictures, and then shrink the pictures. Soldiers were also required to drive the robot to three different waypoints while writing sequential numbers (starting with the number “1”) on a sheet of paper. These tasks required simultaneous task accomplishment, the accomplishment of a task while another task was being performed (the secondary task of writing numbers on a sheet of paper while maneuvering the robot), and the activation of menu items found in second and third tiers of the MOCU menu. Tasks were counterbalanced by having Soldiers with odd roster numbers perform the tasks using speech control first and Soldiers with even roster numbers perform the tasks using manual control first. All tasks were timed.

2.3.5 Experimental Design

The experiment was a repeated measure, within subjects design. The independent variable was the type of robotic control (speech or manual). Dependent variables included the following:

- Time to perform each task with and without speech control
 - Number and type of initial incorrect control inputs for each task on the initial intuition test
 - Number and type of initial incorrect control inputs for each task on the intuition test after training
 - Data collector comments
 - Questionnaire ratings and comments
-

3. Results

3.1 Analysis

All objective data collected during the speech control task event were analyzed using paired comparison *t*-tests. Cohen’s *d*, an index of effect size, was computed for each *t*-test. Iteration effects were controlled through the counterbalanced order of the experimental design. Soldier questionnaire data were analyzed using descriptive statistics on the subjective ratings.

3.2 Demographics

The participants came from a variety of military occupational specialties and jobs including Infantry, Ranger instructor, pathfinder instructor, team leader, medic, combat engineer, and air assault instructor. The mean number of months the Soldiers had been deployed in a combat area

was 15. Twenty-four of the Soldiers were right handed. Two wore contacts and two wore glasses. Only one had robotic experience and that was with a surgical robot. The Soldiers rated their skill level with commercial video games as intermediate.

3.3 Control Intuitiveness Test

Table 1 presents the most frequent phrases suggested by the Soldiers to command the robot in the situations presented. The first column presents the hypothetical situations presented to the Soldiers. The second column presents the current command phrases used to operate the robot in those situations. The phrases suggested by the Soldiers to command the robot in the situations presented are found in the third column and number of Soldiers who suggested each phrase are in the fourth. A complete table containing all the responses can be found in appendix B.

Table 2 shows the nouns and verbs that were most frequently used by the Soldiers compared to the nouns and verbs being used in the current command phrase. A complete table containing all the responses can be found in appendix C.

Table 3 shows the number of Soldiers who responded with the correct command phrase to the hypothetical situations after training and after completion of the timed simulation. A complete listing of all the responses given by the Soldiers after training can be found in appendix D.

Table 1. Most frequent phrases suggested by Soldiers for the hypothetical situations.

Hypothetical Situation	Current Command Phrase	Most Frequent Suggested Phrase	No. of Soldiers Suggesting the Phrase
a. You're in a remote location from the robot and see an item that may be of military interest on the screen. You're not sure that you recognize the item and you want to save an image of it to look at it later. What do you tell the robot to do?	Take picture	Take picture	17
		Capture image	3
		Take photo	2
		Take image	2
b. You have a picture of an item on the robot display and you want to name it "A" (Alpha) so you can later identify it to the robot. What do you tell the robot to do?	Label alpha	Label alpha	12
		Save picture, label alpha	2
		Name image alpha	2
c. You want to put the robot in a mode that will allow you to use the mouse to draw an area on the map that is dangerous (IED's are present). By drawing this area on the map, it will keep the robot from entering the area. How do you tell the robot to allow you to draw in this mode?	Activate exclusion zone	Draw mode	4
		Draw	2
		Avoid area	4
d. You have completed the drawing, are satisfied with it, and want the robot to keep out of the area. What do you tell the robot to do?	Execute exclusion zone	Danger area	2
		Stay out of area	2
		Stay clear	2
		Draw route	2
e. You want to place a line on the map to show that you want the robot to travel along the line from waypoint "A" to waypoint "B." What do you tell the robot to do?	Add route	Draw line	2
		Delete point	6
		Remove point	4
f. The robot is looking around on its own in the autonomous mode and it has generated multiple dots on the map. These dots show you where the robot intends to go. One of the points is in an area where you know IEDs are present and you <u>never</u> want the robot to go in that area. You want the point to be completely removed from the map. What do you tell the robot to do?	Remove goal	Delete waypoint	2
		Prioritize point(s)	4
		Disregard point	2
g. You know generally where enemy activity is the highest and one of the points that the robot generates to let you know where it is going is not as important as the others. You want the robot to go to the other points first but don't want to completely remove the point from the map	Skip a goal	Autonomous mode	3
		Scan area	3
		Scan sector	2
		Roam	2
h. You want the robot to start looking around on its own. What do you tell the robot to do?	Activate self exploration	Show position	3
		Give location	3
		ID location	2
		Location	2
i. You are in map view and want to show where the robot is located on the map. What do you tell the robot to do?	Locate the position of the robot on the map	Return [to] start point	6
		Return	5
		Return to start	3
		Return to base	3
j. You want the robot to come back where it started from. What do you tell the robot to do?	Return home/retrotraverse	Turn right	10
		Move right	4
		Go right	3
		Enter door on right	2
k. The robot is driving straight ahead. It's going to hit the wall if it keeps going in that direction. You want it to go through the door directly to the right of the robot. What do you tell the robot to do?	Right turn	Turn right	10
		Move right	4
		Go right	3
		Enter door on right	2

Table 2. Parts of speech comparison.

Current Command Phrase	Verb	No. of Soldiers Using Word	Noun or adjective/noun	No. of Soldiers Using Word
a. Take picture	take	21	picture	17
	capture	4	image	8
b. Label alpha	label	17	alpha	26
	name	6	picture	6
	save	6	image	5
c. Activate exclusion zone	draw	6	draw mode	5
	allow	2	danger area	4
d. Execute exclusion zone	stay	7	area	8
	avoid	4	danger area	4
e. Add route	draw	5	line	8
	travel	4	route	7
	follow	4	“A”, “B”, alpha or bravo	6
	input	2	waypoint	4
	move	2	point	2
	execute	2	—	—
	delete	9	point	14
f. Remove goal	remove	6	waypoint	3
	exclude	2	area	2
	avoid	2	danger point	1
	prioritize	5	point(s)	12
g. Skip a goal	go	3	priority	5
	recon	7	autonomous mode	4
h. Activate self exploration	roam	2	autonomous search	2
	—	—	sector	2
	—	—	area	3
	give	4	location	9
i. Locate the position of the robot on the map	id	5	position	6
	display	2	current location	2
	show	4	point	2
	locate	2	—	—
	return	18	start point	7
j. Return home/retro traverse	—	—	start	4
	—	—	Home	3
	—	—	base	3
	turn	12	right	22
k. Right turn	go	4	door[way]	4
	move	4	—	—

Table 3. Phrases used by Soldiers in response to hypothetical situation after training.

Current Command Phrase	Number of Soldiers Using the Phrase
a. Take picture	21
b. Label alpha	24
c. Activate exclusion zone	0
d. Execute exclusion zone	0
e. Add route	0
f. Remove goal	1
g. Skip a goal	2
h. Activate self exploration	10
i. Locate the position of the robot on the map	10
j. Return home/retrotraverse	14
k. Right turn	18

The majority of the Soldiers thought that “Take picture” was the most intuitive phrase for situation “a.” Once trained, all of the Soldiers but four remembered the current command phrase. Thus, Soldiers and the programmers of the current command phrase were in agreement that the phrase was intuitive and easy to remember.

A little less than half of the Soldiers thought that “Label alpha” was the most intuitive phrase for situation “b.” The most frequently suggested verbs, in order, were “label,” “name,” and “save”. While the most frequently used noun was “alpha,” many Soldiers used a noun designator before the word “alpha” (i.e., “Label picture alpha,” “Label image alpha,” etc.). In this situation, the designator is not necessary, because the picture is chosen on the display and the phrase “Label alpha” is more efficient. After being trained, all but one Soldier remembered the current phrase.

None of the Soldiers responded with the correct phrase during the intuition phase of the experiment and none remembered the current command phrase for situation “c” after being trained. The most common response to the situation during the intuition phase was “Draw mode.” This phrase shows that the Soldiers’ schemas put the system into a drawing mode similar to the way that Microsoft Windows lets them choose to draw a line or a shape. The command “Draw mode” would allow more flexibility for situation “c” and other situations that require the Soldier to draw or write on the map area.

None of the Soldiers responded with the current command phrase for situation “d” during the intuitive phrase or after being trained. “Exclusion zone” is not a phrase typically used by the military. Soldiers frequently called the off-limits section an area, a danger area, or a danger zone. The most frequent verbs used were avoid, stay out, and stay clear. Designers of the current phrases for situations “c” and “d” were more specific than the Soldiers. They programmed the system to create a specific item (exclusion zone). The Soldiers, on the other hand, thought in terms of telling the system to go into a drawing mode and then telling the system what the drawing meant (how to treat the drawing). The designers then told the system to

execute a specific command while the Soldiers told the robot to stay out of an area that was drawn because of what it was labeled. “Avoid danger area” would be a more intuitive command for Soldiers than “Execute exclusion zone.” An even more efficient command would be “Draw danger area” for situations “c” and “d.” The word “draw” would put the system into the drawing mode and the words “danger area” would command the system to label the drawn area and avoid the area.

Situation “e” was similar to situations “c” and “d.” None of the Soldiers used the current command phrase “Add route” during the intuition phase or after being trained. The most common response during the intuition phase was “Draw route.” This word “draw” would also put the system into the drawing mode and the word “route” would command the system to label the drawn line as a route and to treat it as such.

The current command phrase for situation “f” was “Remove goal.” While none of the Soldiers responded with that phrase, it was primarily because they were not familiar with the concept of intended goals for the robot (areas that the robot intended to explore during autonomous search). The most common response was “Delete point.” The verb “delete” was used nine times while the verb “remove” was used six times. Once the Soldiers were trained on the concept of goals, they still did not remember the current command phrase. In fact, only three of them even used the word “goal.” The word “point” was still the most commonly used noun, even after training.

Again for situation “g,” the Soldiers did not understand the concept of a goal during the intuition phase. None of the Soldiers responded with the current command phrase during the intuition phase and only two responded with the correct phrase after training. The most commonly used noun was the word “point.” Soldiers also did not think in terms of “skipping a goal.” Instead, they thought more in terms of “prioritizing points” during the intuition phase.

The words the Soldiers used most frequently for situation “h” did not adequately describe what the robot needed to do. The most popular verb used was “scan” and this verb is more commonly associated with panning a camera rather than driving around to explore an area. They also used unexplained nouns (e.g., area, sector, and perimeter) as adverbs. The most frequently used noun was “autonomous” and this was not an adequate word, since the robot was already in the autonomous mode. The current command phrase (activate self exploration) was not chosen initially, but after training, 10 of the Soldiers used the correct command phrase. During the intuition phase, a few of the Soldiers suggested that the words “recon” or “recon mode” be used and this would probably be the most descriptive phrase and the one that would be closest to military phraseology.

The current command phrase for situation “i” (Locate the position of the robot on the map) is quite wordy. The Soldiers’ suggestions during the intuition phase were much terser. The word “position” was the most frequently used noun and the verbs “give,” “ID,” and “show” were the most frequently used verbs. The phrase “show position” would be adequate if the display was in map view. The current command phrase was remembered by 10 of the Soldiers after training.

While only one Soldier suggested using the word “ping,” it would be the most descriptive and efficient way to get the idea across. The word “ping” is used in the naval world, the gaming world, and the computer world. In the naval and gaming lexicon, “ping” comes from a submarine sonar search. A short sound burst is sent and an echoing ping returns so the submariner knows where the object pinged is located (range to the target). In the computer world, “ping” is a program that allows a user to verify that another computer is reachable by sending it a message and waiting for an acknowledgment. Before this word is chosen, research would be needed to determine if the Soldier target audience readily understands its meaning.

For situation “j” the current command phrase was “Return home/retrotraverse.” Two Soldiers suggested using just “Return home;” none used the word retrotraverse during the intuition phase. The verb “return” was used by 17 of the Soldiers in the intuition phase, while the most frequently used noun was “start/start point.” Fourteen of the Soldiers remembered “Return home/retrotraverse” after training.

For situation “k” the current command phrase was “Right turn.” Ten of the Soldiers suggested “Turn right” and almost all of the Soldiers put their suggested verb in front of the direction. Even after being trained on the current phrase, seven of the Soldiers still placed the verb before the noun. In fact, during the entire intuition phase, the vast majority of the Soldiers placed the verb first in their suggested phrase for every command in each of the situations.

3.4 Training

Soldiers felt that the speech-based control training was very good. Their ratings are shown in table 4.

Table 4. Soldiers’ ratings of the training.

Category	Mean Rating
Completeness of speech training	5.78
Comprehension of the concept of the speech control	5.88
Overall evaluation of the speech training course	5.81

One of the 29 Soldiers participating in the evaluation indicated that he needed a little more practice. Another rated the training as neutral, because he had difficulty pronouncing the words (English was his second language). Three Soldiers indicated that the manual controller was the hardest training task to learn and two indicated that the speech control was the hardest task.

Twenty-eight out of the 29 Soldiers who trained on the speech-control system were easily understood by it. (One Soldier’s voice had a compatibility issue with the microphone being used and did not participate in the evaluation. That issue has since been resolved.) Forty sentences were used to train the system to the Soldiers’ voices and this was accomplished in 7 to 10 min.

3.5 Speech Control Tasks

The average times to complete tasks using verbal and manual control are shown in table 5. Table 6 is a summary of the paired-sample t -tests used to compare the mean verbal and manual values for each task. Holm's Bonferroni procedure was used to control for family-wise error. Cohen's d is an index of effect size, the difference in the two means divided by the pooled SD . For the photographic tasks, the verbal control was faster than the manual control for all tasks except taking the photograph (this task required moving the robot into position in order to take the picture). The manual control was significantly faster for taking the photograph. There was no significant difference between the times required to drive to the waypoints.

Table 5. Mean times to complete tasks.

Task	Verbal		Manual	
	Mean (s)	SD	Mean (s)	SD
Take a picture	15.5	3.1	13.4	3.2
Label the picture	3.8	1.4	7.7	3.3
Enlarge the picture	2.8	1.7	5.7	1.7
Shrink the picture	2.1	0.9	6.2	2.6
Drive to two waypoints	133.6	47.3	119.4	21.0

Table 6. Summary of paired-sample t -tests.

Task	t	df	obtained p	required p	d
Take a picture	2.87	28	0.008 ^a	0.025	0.65
Label the picture	-5.23	28	< 0.001 ^a	0.0167	1.54
Enlarge the picture	-7.74	28	< 0.001 ^a	0.0125	1.78
Shrink the picture	-7.83	28	< 0.001 ^a	0.010	2.11
Drive to two waypoints	1.60	28	0.12	0.050	0.39

^a $p < 0.05$, 2-tailed

Table 7 summarizes the secondary task (the mean number of numbers written on the paper while driving to the waypoints). Performance on the secondary task (writing down numbers) while driving was significantly better with the verbal control. Table 8 is a summary of the paired-sample t -test used to compare the mean verbal and manual values for the secondary task.

Table 7. Mean numbers written per second while driving.

	Verbal		Manual	
	Mean	SD	Mean	SD
Numbers per second	0.47	0.14	0.39	0.13

Table 8. Summary of paired-sample t -test.

Task	t	df	p	d
Numbers per second	3.671	28	0.001 ^a	0.59

^a $p < 0.05$, 2-tailed.

4. Discussion and Recommendations

This experiment demonstrated how important it is to tailor speech commands to the target audience. Before training, less than 10% of the commands the Soldiers thought should be used were the commands that were programmed into the speech-control system. Even after training and using many of the commands during a simulation task, only 34% of the Soldiers remembered the commands that the system designers programmed. Commands that were initially intuitive (“Take picture” and “Label alpha”) were correctly used by 72% and 83%, respectively, of the Soldiers after training. Conversely, less intuitive phrases such as “Activate exclusion zone” were not remembered by any of the Soldiers, even after training. Thus, we determined that it is important to develop intuitive command phrases that are based on military phrases and the Soldiers’ schemas, because doing so would result in fewer errors and reduce the time it takes Soldiers to perform robotic tasks, especially during times of combat stress and high cognitive load.

The use of grammatical rules or language models to organize the command words would help make them more meaningful and easier for the Soldiers to remember. For example, interestingly, the vast majority of the Soldiers placed the verb first in their suggested command phrases. A simple rule that states “always place the verb before the noun” would be a good rule to institute, because it would provide consistency and follow what the Soldiers tend to do naturally. The verb tells the robot what behavior it should perform and the following word tells the robot where or how it should perform the behavior. “Turn” tells the robot that it will change directions and “right” tells the robot which direction. “Draw” tells the robot to go into the drawing mode and “danger area” tells the robot what the resulting drawing is and how to treat the drawing. “Forward” tells the robot to move in a forward direction and “10 ft” tells the robot how far to go forward. “Go” tells the robot to turn on the driving behavior and “home” tells the robot where it is suppose to drive. These “rules” should be as consistent as possible with the Soldiers’ natural language and be consistent between commands.

For the photographic tasks, the verbal control was faster than the manual control for all tasks except taking the photograph. The manual control was significantly faster for taking the photograph, because this task required driving the robot into position in order to take the picture. This is consistent with the literature, because driving has been shown to be more efficient with manual control than with speech-control (Pettitt et al., 2009). A continuous task such as turning requires either starting a behavior that continues until stopped (having to stop the second the robot gets into the correct position with no lag) or repeating a command multiple times (if the robot only turns a few degrees each time it is told to turn). The mean driving time was larger for speech control than for manual control, but there was no significant difference between the total times, partially because of the large variance in driving times using speech control. However,

when the driving times for each single waypoint were compared, the manual control was significantly faster for driving to the blue waypoint, but this result was not true for the green waypoint. This difference might be explained by the fact that driving to the blue waypoint required greater maneuvering around an obstacle that was located directly in front of the unmanned ground vehicle (UGV). This setup forced the Soldiers to do a lot of turning and negotiating. Driving to the green waypoint was primarily a straight route that only required slight turns around the obstacle.

Overall, all three of our hypotheses were met:

1. Soldiers were able to perform a secondary task (writing numbers) significantly faster when operating the robot using speech control than they were when operating the robot using manual control. It is clear that robotic control requires multitasking. It also appears that speech control required less attention than manual control, thus freeing up cognitive resources for additional tasks.
2. Speech control allowed significantly faster task performance than manual control when the task involved the use of menu items (enlarge picture, shrink picture). Speech control allowed direct access to the menu items, while manual control required navigating through a menu and selecting an item that was two levels deep into the menu. Speech control was also significantly faster for labeling items in which Soldiers had to choose a list and then select Alpha, Bravo, Charlie, Delta, or Echo from the list to label the picture.
3. Speech control took significantly longer when performing continuous tasks such as turning the robot during the “take a picture” task and driving to the blue waypoint, which involved a significant amount of turning.

When interpreting the results, it is important to consider the tasks that were examined during this experiment. The tasks used in the intuition and speech-control portions of the experiment were tasks that could be found in a robotic reconnaissance mission and the findings are specific to these tasks.

5. Conclusions

- It is extremely important to tailor speech commands to the target audience. Tailoring allows better retention and more efficient operation.
- Speech control is quicker than manual control in situations that require secondary task accomplishment and also in situations in which the items that need to be accessed are embedded in menus.
- Manual control is more effective than speech control for non-discrete tasks such as turning.

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Appendix A. Demographics Questionnaire

This appendix appears in its original form without editorial change.

Sample Size = 29

MOS	RANK	DUTY POSITION		
09S – 10	68D – 1	E4 – 6	Air Aslt Instructor – 1	Pathfinder Instructor - 1
11B – 8	68W – 1	E5 – 17	Crew Chief – 1	Ranger Instructor – 1
11C – 1	88M – 2	E6 – 2	Driver – 1	Support – 1
12B – 1	OCS – 3	OCS – 4	Instructor – 1	Team leader – 4
15T – 1			Medic – 1	Training – 1
31B – 1			OCS – 7	NR - 8
			Combat Engr - 1	

AGE

28 years (range 21-47)

1. How long have you served in the military? 65 months (mean)
2. How long have you had an infantry-related job? 72 months (mean)
3. How long have you been a fire team leader? 21 months (mean)
4. How long have you been a squad leader? 44 months (mean)
5. How long have you been deployed overseas? 21 months (mean)
6. How long have you been deployed in a combat area? 15 months (mean)
7. With which hand do you most often write? 24 Right 5 Left
8. With which hand do you most often fire a weapon? 26 Right 3 Left
9. Do you wear prescription lenses? 4 Yes 25 No
10. If yes, which do you wear most often? 2 Glasses 2 Contacts
11. Which is your dominant eye? 25 Right 4 Left
12. Do you have any vision related problem? 2 Yes 27 No
If so, what? Red/green color blind (1), farsighted (1)
13. Have you ever used a robotic system? 1 Yes 23 No 5 NR
If so, what type? Davinci (1)
14. Please describe the conditions under which you used the robotic system.
Surgical (1)

15. Using the scale below, please rate your skill level for each of the following activities.

None 1	Beginner 2	Intermediate 3	Expert 4
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ACTIVITY	MEAN RESPONSE
Operating ground unmanned vehicles	1.13
Operating aerial vehicles	1.09
Target detection and identification	1.55
Playing commercial video games	2.65
Training with Army video simulations	2.17

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Appendix B. Phrases Suggested by Soldiers for the Hypothetical Situations

This appendix appears in its original form without editorial change.

(Note that not all responses add to 29 as sometimes Soldiers responded more than once and others times some Soldiers did not respond.)

Hypothetical Situation	Current Command Phrase	Soldier's Suggested Command Phrase	Number of Soldiers Suggesting the Phrase
a. You're in a remote location from the robot and see an item that may be of military interest on the screen. You're not sure that you recognize the item and you want to save an image of it to look at it later. What do you tell the robot to do?	Take picture	Take picture Take photo Take image Image Capture image Capture Save image	17 2 2 1 3 1 2
b. You have a picture of an item on the robot display and you want to name it "A" (Alpha) so you can later identify it to the robot. What do you tell the robot to do?	Label alpha	Label alpha Name alpha Save alpha Save picture, label alpha Save picture alpha Label off Label image Label image alpha Save as image alpha Save as alpha Label picture alpha Name image alpha Name picture alpha Save photo as alpha Name alpha Name picture	12 1 1 2 1 1 1 1 1 1 1 1 1 2 1 1 1 1 1 1
c. You want to put the robot in a mode that will allow you to use the mouse to draw an area on the map that is dangerous (IED's are present). By	Activate exclusion zone	Draw mode Allow draw mode Draw Draw map Draw line	4 1 2 1 1

Hypothetical Situation	Current Command Phrase	Soldier's Suggested Command Phrase	Number of Soldiers Suggesting the Phrase
drawing this area on the map, it will keep the robot from entering the area. How do you tell the robot to allow you to draw in this mode?		Draw picture Observe and draw Manual draw Manual mode Allow mouse Mouse control Use mouse Mouse mode Mouse Danger zone Danger area Label danger area Enter danger area Danger area drop Restricted mode Quarantine mode Map restrictions Shade area on map Proceed avoiding dangerous map display Flag area Standby	1 1
d. You have completed the drawing, are satisfied with it, and want the robot to keep out of the area. What do you tell the robot to do?	Execute exclusion zone	Avoid area Restricted area Restrict area Danger area Exit danger area Keep out of danger area Danger area lock Designate area Steer clear Stay out of area Stay Stay out of shaded area Stay out of selected area Stay clear	4 1 1 2 1 1 1 1 1 2 1 1 1 1 1 2

Hypothetical Situation	Current Command Phrase	Soldier's Suggested Command Phrase	Number of Soldiers Suggesting the Phrase
		Keep out of area	1
		Keep out of exclusion zone	1
		Do not enter map	1
		Follow last map restrictions	1
		Send drawing	1
		Follow instructions	1
		Area forbidden	1
		Seek hull defilade	1
e. You want to place a line on the map to show that you want the robot to travel along the line from waypoint “A” to waypoint “B.” What do you tell the robot to do?	Add route	Draw route	3
		Draw line	2
		Draw waypoint	1
		Input path	1
		Input line	1
		Line	1
		Mouse control	1
		Mark point	1
		Yellow route designated	1
		Drive route	1
		Follow route	1
		Follow line	1
		Travel line	1
		Travel on dark line	1
		Move from point “A” to point “B”	1
		Travel from “A” to “B”	1
		Travel “A” to “B”	1
		Traverse from route “A” to “B”	1
		Follow waypoint “A” to waypoint “B”	1
		Go from waypoint alpha to bravo	1
		Move to waypoint	1

Hypothetical Situation	Current Command Phrase	Soldier's Suggested Command Phrase	Number of Soldiers Suggesting the Phrase
		Execute last trace	1
		Execute exclusions	1
		Follow directions	1
		Standby	1
		Scroll to line	1
f. The robot is looking around on its own in the autonomous mode and it has generated multiple dots on the map. These dots show you where the robot intends to go. One of the points is in an area where you know IEDs are present and you <u>never</u> want the robot to go in that area. You want the point to be completely removed from the map. What do you tell the robot to do?	Remove goal	Delete point	6
		Delete waypoint	2
		Remove point	4
		Remove waypoint	1
		Remove exclusion point	1
		Exclude point	1
		Avoid point	1
		Avoid dot on map	1
		Modify route	1
		Delete area	1
		Do not enter	1
		Eliminate points or direction	1
		Input path	1
		Filter last overlay	1
		Cancel movement	1
		Mark restricted area	1
		Restrict area	1
g. You know generally where enemy activity is the highest and one of the points that the robot generates to let you know where it is going is not as important as the others. You want the robot to go to the other points first but don't want to completely remove the point from the map. What do you tell the robot to do?	Skip a goal	Prioritize point(s)	4
		Prioritize on my command	1
		Priority low	1
		Follow by priority	1
		Priority area	1
		Low priority	1
		Reorganize priority	1
		Set priority	1
		Priority point	1
		Disregard point	2
		Sequence points	1
		Go to high activity points	1

Hypothetical Situation	Current Command Phrase	Soldier's Suggested Command Phrase	Number of Soldiers Suggesting the Phrase
		Go to another point	1
		Remove point	1
		Hold point	1
		Skip point	1
		Stop and mark waypoint	1
		Stop and redirect	1
		Redirect	1
		Follow by interest level	1
		Go around	1
		Detour	1
		Reverse order	1
		Do not enter	1
h. You want the robot to start looking around on its own. What do you tell the robot to do?	Activate self exploration	Roam	2
		Autonomous mode	3
		Perform autonomous mode	1
		Autonomous search mode	1
		Autonomous search	1
		Enter autonomously	1
		Scan area	3
		Scan sector	2
		Scan around	1
		Begin scan	1
		Scan	1
		Area recon	1
		Recon mode	1
		Recon	1
		Self mode	1
		Auto pilot	1
		Set up patrol of perimeter area	1
		Search perimeter	1
		Explore	1

Hypothetical Situation	Current Command Phrase	Soldier's Suggested Command Phrase	Number of Soldiers Suggesting the Phrase
		Unassisted	1
		Go free	1
		Site survey	1
i. You are in map view and want to show where the robot is located on the map. What do you tell the robot to do?	Locate the position of the robot on the map	Ping	1
		Display current location	1
		Location	2
		Location point	1
		Transmit location	1
		Plot location	1
		Give location	3
		Current location	1
		ID location	2
		ID self	1
		ID robot	1
		ID on map	1
		ID locate	1
		Locate point	1
		Drop point	1
		Show position	3
		Show current position	1
		Mark your position	1
		Give position	1
		Display position	1
		Map view	1
j. You want the robot to come back where it started from. What do you tell the robot to do?	Return home/retrotraverse	Return to start	3
		Return [to] start point	6
		Return to base	3
		Return to loading point	1
		Return home	2
		Home	1
		Return	5
		Go back to start point	1
		Go to starting point	1
		Restart	1

Hypothetical Situation	Current Command Phrase	Soldier's Suggested Command Phrase	Number of Soldiers Suggesting the Phrase
		Starting	1
		Alignment start point	1
		Locate origin	1
		Reset	1
		Reverse	1
k. The robot is driving straight ahead. It's going to hit the wall if it keeps going in that direction. You want it to go through the door directly to the right of the robot. What do you tell the robot to do?	Right turn	Turn right	10
		Turn	1
		Go right	3
		Move right	4
		Take [a] right	1
		Right door	1
		Reroute direction	1
		Redirect through doorway	1
		Enter door on right	2
		Turn 45 degrees	1
		Right 90 degrees	1
		Right go	1

Appendix C. Parts of Speech Comparison

This appendix appears in its original form without editorial change.

Current Command Phrase	Verb	No. of Soldiers Using Word	Noun or adjective/noun	No. of Soldiers Using Word
a. Take picture	take	21	picture	17
	capture	4	image	8
	save	2	photo	2
b. Label alpha	label	17	alpha	26
	name	6	picture	6
	save	6	image	5
			photo	1
c. Activate exclusion zone	draw	6	draw mode	5
	label	1	manual mode	1
	allow	2	restricted mode	1
	observe	1	quarantine mode	1
	use	1	mouse mode	1
	enter	1	mouse control	1
	drop	1	mouse	2
	shade	1	danger area	4
	proceed	1	danger zone	1
	flag	1	map restrictions	1
	standby	1	area	2
			dangerous map display	1
d. Execute exclusion zone	avoid	4	area	8
	stay	7	danger area	4
	restrict	1	restricted area	1
	designate	1	Shaded area	1
	exit	1	Selected area	1
	keep	2	map	1
	steer	1	map restrictions	1
	enter	1	drawing	1
	follow	1	instructions	1
	send	1	hull defilade	1
	seek	1		
e. Add route	draw	5	line	8
	travel	4	route	7
	follow	4	“A”, “B”, alpha or bravo	6
	input	2	waypoint	4
	move	2	point	2
	execute	2	path	1

Current Command Phrase	Verb	No. of Soldiers Using Word	Noun or adjective/noun	No. of Soldiers Using Word
	scroll	1	mouse	1
	drive	1	trace	1
	go	1	exclusions	1
	traverse	1		
	stand	1		
f. Remove goal	delete	9	point	14
	remove	6	waypoint	3
	exclude	2	exclusion point	1
	avoid	2	danger point	1
	eliminate	1	area	2
	modify	1	restricted area	1
	enter	1	route	1
	input	1	direction	1
	filter	1	overlay	1
	cancel	1	movement	1
	mark	1	path	1
g. Skip a goal	restrict	1	dot	1
	prioritize	5	point(s)	12
	go	3	priority	5
	stop	2	priority area	1
	follow	2	priority point	1
	disregard	2	waypoint	1
	sequence	2	command	1
	redirect	2	order	1
	hold	1	interest level	1
	mark	1		
	reorganize	1		
	remove	1		
	detour	1		
	enter	1		
h. Activate self exploration	reverse	1		
	set	1		
	skip	1		
	scan	1	autonomous mode	4
	recon	7	autonomous search	2
	roam	2	auto pilot	1
	enter	1	area recon	1
	explore	1	recon mode	1

Current Command Phrase	Verb	No. of Soldiers Using Word	Noun or adjective/noun	No. of Soldiers Using Word
	set	1	self mode	1
	search	1	sector	2
	perform	1	area	3
	go	1	perimeter	1
	survey		site	1
			perimeter area	1
			patrol	1
i. Locate the position of the robot on the map	give	4	location	9
	id	5	location point	1
	display	2	current location	2
	transmit	1	current position	1
	plot	1	position	6
	show	4	point	2
	drop	1	map	1
	mark	1	robot	1
	locate	2	self	1
			map view	1
j. return home/retrotraverse	return	18	home	3
	go back	1	start point	7
	restart	1	starting point	1
	starting	1	start	4
	alignmen t	1	loading point	1
	locate	1	base	3
	reset	1	origin	1
k. right turn	turn	12	right	22
	go	4	direction	1
	move	4	45 degrees	1
	take	1	90 degrees	1
	enter	2	door[way]	4
	reroute	1		
	redirect	1		

Appendix D. Phrases used by Soldiers in Response to Hypothetical Situations after Training

This appendix appears in its original form without editorial change.

Hypothetical Situation	Current Command Phrase	Soldier's Command Phrase After Training	Number of Soldiers Suggesting the Phrase
a. You're in a remote location from the robot and see an item that may be of military interest on the screen. You're not sure that you recognize the item and you want to save an image of it to look at it later. What do you tell the robot to do?	Take picture	Take picture Label alpha Save picture Take image	21 1 2 1
b. You have a picture of an item on the robot display and you want to name it "A" (Alpha) so you can later identify it to the robot. What do you tell the robot to do?	Label alpha	Label alpha Save alpha	24 1
c. You want to put the robot in a mode that will allow you to use the mouse to draw an area on the map that is dangerous (IED's are present). By drawing this area on the map, it will keep the robot from entering the area. How do you tell the robot to allow you to draw in this mode?	Activate exclusion zone	Something mode Draw Draw area Mark area Exclusion out Robot control No response	1 1 1 1 1 1 19
d. You have completed the drawing, are satisfied with it, and want the robot to keep out of the area. What do you tell the robot to do?	Execute exclusion zone	Keep in boundary Execute Avoid area Do not enter Exit area Exclude area Follow route Exclusion Go around exclusion point Keep out Exclude point Keep out mode Skip area No response	1 2 2 1 1 1 1 1 1 1 1 1 1 1 10
e. You want to place a line on the map to show that you want the robot to travel along the	Add route	Go to route Draw line Draw waypoint	1 2 2

Hypothetical Situation	Current Command Phrase	Soldier's Command Phrase After Training	Number of Soldiers Suggesting the Phrase
line from waypoint “A” to waypoint “B.” What do you tell the robot to do?		Execute route Travel to “A” point “A” Follow points/add points Follow route Go to point Remove execution point Drive forward No response	1 1 1 2 1 1 1 1 12
f. The robot is looking around on its own in the autonomous mode and it has generated multiple dots on the map. These dots show you where the robot intends to go. One of the points is in an area where you know IEDs are present and you <u>never</u> want the robot to go in that area. You want the point to be completely removed from the map. What do you tell the robot to do?	Remove goal	Remove goal Delete point Remove point Delete waypoint Remove Eliminate point Stay out of execution area Remove execution point Remove exclusion point Lead point Cancel goal Danger Delete goal No response	1 3 5 3 1 1 1 1 1 1 1 1 1 1 4
g. You know generally where enemy activity is the highest and one of the points that the robot generates to let you know where it is going is not as important as the others. You want the robot to go to the other points first but don't want to completely remove the point from the map. What do you tell the robot to do?	Skip a goal	Skip a goal Do not enter Ignore point Skip point Avoid Go around exclusion point Avoid point Ignore goal Reverse point Low priority No response	2 1 1 5 1 1 1 1 1 1 9
h. You want the robot to start looking around on its own.	Activate self exploration	Activate self exploration	10

Hypothetical Situation	Current Command Phrase	Soldier's Command Phrase After Training	Number of Soldiers Suggesting the Phrase
What do you tell the robot to do?		Robot search Search around Search area Explore Scan mode Auto pilot No response	1 1 2 1 1 1 7
i. You are in map view and want to show where the robot is located on the map. What do you tell the robot to do?	Locate the position of the robot on the map	Locate the position of the robot on the map Find robot Robot location Route robot Show point Locate Location ID mode Give position Show location Mark position No response	10 1 2 1 1 1 1 1 1 1 1 4
j. You want the robot to come back where it started from. What do you tell the robot to do?	Return home/retrotraverse	Return home/retrotraverse Return home Return to start point Come home Come back Return No response	14 3 2 2 1 1 2
k. The robot is driving straight ahead. It's going to hit the wall if it keeps going in that direction. You want it to go through the door directly to the right of the robot. What do you tell the robot to do?	Right turn	Right turn Turn right Go right Stop-turn right	18 5 1 1

List of Symbols, Abbreviations, and Acronyms

ARL	U.S. Army Research Laboratory
ASR	automated speech recognition
COTS	commercial-off-the-shelf
HRED	Human Research and Engineering Directorate
MOCU	Multi-Robot Operator Control Unit
OCS	Officer Candidate School
SCR	speech command recognition
TAM	Think-A-Move, Ltd.

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